Assessment

Forest Plan Revision

Draft Baseline Assessment of Carbon Stocks Report

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for:
Custer Gallatin National Forest

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Introduction

The 2012 Planning Rule and agency directives state that the responsible official shall identify and assess available information relevant to the plan area for baseline assessment of carbon stocks (36 CFR 219.6(b)(4)). A baseline assessment estimates existing carbon stocks and recent changes in carbon stocks on the land and in harvested wood products. A broad-scale (regional) and mid-scale (national forest) level assessment of carbon stocks for the Northern Region has been done and is used for this assessment effort for the Custer Gallatin National Forest (USDA Forest Service 2015a). Carbon stocks are defined as the amount or quantity contained in the inventory of a carbon pool.

The responsible official should use the assessment of carbon stocks to understand how:

1. the plan area plays a role in sequestering and storing carbon;
2. disturbances, projects, and activities influence carbon stocks in the past and may affect them in the future; and
3. where the carbon is stored, how the storage is changing, and how the storage might be influenced by management.

The primary relationship between forests, forest management, and climate change is the role forests play in the atmospheric carbon cycle, as displayed in Figure 1. Forests cycle carbon and are in continual flux. Carbon is removed from the atmosphere through photosynthesis, which sequesters it in the form of biomass. Carbon is emitted through respiration and the decay of organic matter. The cycle is influenced by release of carbon into the atmosphere from dead trees and vegetation which contribute to disturbance events such as wildfire, insects and wind throw. Site productivity influences the potential of a site to support vegetation, which is linked to soil carbon. Decomposition of woody debris and forest litter adds carbon to the soil. This addition to soil carbon can be lost through disturbance events such as wildfire or management actions such as timber harvest.

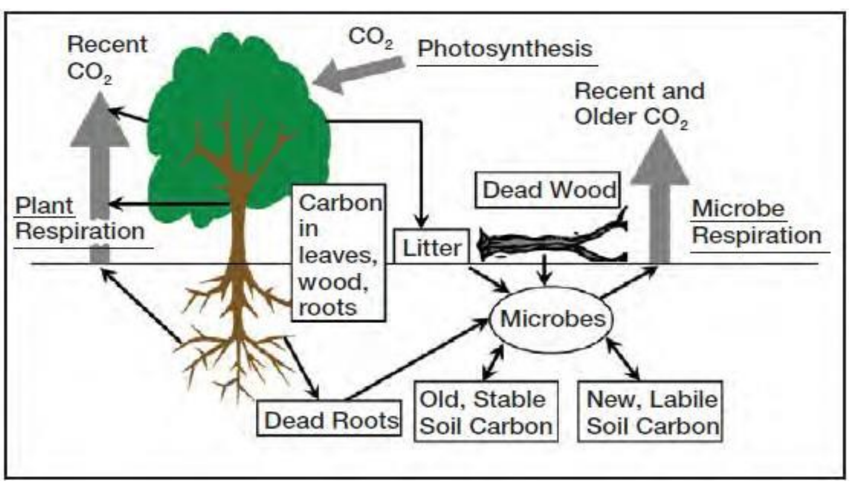

Figure 1. Flows of carbon from the atmosphere to the forest and back in (Ryan et al. 2010)

Through one or more cycles of disturbance and regrowth, net carbon storage is often zero because regrowth of trees recovers the carbon lost in the disturbance and decomposition of vegetation in the long term (Ryan et al. 2010; Kashian et al. 2006). Carbon storage and sequestration rates are more stable over large areas that comprise a multitude of forests of different ages. With multiple stands in different stages of recovery after disturbance, some stands provide a carbon “sink” while others act as net “sources” (Ryan et al. 2010). Changes in the frequency or severity of disturbance regimes over large areas can increase or lower the average carbon stocks in forests (Kashian et al. 2006).

Carbon sequestration is one way to mitigate greenhouse gas emissions by offsetting losses through capture and storage of carbon and the Forest Service recognizes the vital role that our nation’s forests and grasslands play in carbon sequestration (USDA Forest Service 2015a).

Process and Methods

A baseline estimate of carbon stocks in the forests and harvested wood products for the National Forest System units in the Northern Region has been compiled by the Climate Change Advisor’s Office for the Office of the Chief in 2015 and is used to portray baseline carbon stocks for the Custer Gallatin National Forest (USDA Forest Service 2015a).

Estimates of forest carbon stocks are based on forest inventory data obtained from the Forest Inventory and Analysis (FIA) program. FIA is the only consistent data set across all ownerships and national forests of the United States. The official reporting tool for interpreting historical FIA data to develop timelines of carbon stock estimates is the Carbon Calculation Tool (USDA Forest Service 2015a). This is currently the best nationally available integration to identify trends in carbon storage. Despite unavoidable uncertainties related to changes in FIA, Carbon Calculation Tool-based assessments of National Forest System carbon stocks represent an objective application of a national carbon accounting system.

Scale

The Forest Service estimated national forest carbon stocks for all 10 regions and documented them in individual whitepapers. For the Northern Region this was further stepped down to the 12 national forest units and 1 national grassland unit for the time period 1990 to 2013 (USDA Forest Service 2015a). This effort was done prior to official administrative consolidation of the Custer and Gallatin National Forests and the findings in this report cannot be broke down into the six separate analysis units. Therefore, this assessment will discuss carbon stocks at the proclaimed national forest level with some reference to the broader Northern Region) scale.

Existing Information Sources

An ever-increasing body of knowledge exists regarding climate change and carbon sequestration. The best available science is used to summarize conditions relative to the Custer Gallatin National Forest. The information sources available include the following:

- Forest Inventory and Analysis (FIA) data: FIA data can be used to generate estimates of carbon stocks on National Forest System lands. The Climate Change Advisor’s Office for the Forest Service recently conducted work to analyze and summarize carbon stock data for the Northern Region (USDA Forest Service 2015a) and the report generated by this work is used for the assessment of baseline carbon stocks. This report provides a basic overall assessment of where carbon is stored at mid to broad scales, and provides basic information for national forests that may lack more detailed data on carbon. Technical documentation to support this report for data sources and modeling procedures for estimating carbon stocks was done by the Forest Service’s Research and Development branch, Northern Region Research Station (Woodall et al. 2013).
- Draft Assessment of the Influence of Disturbance, Management Activities, and Environmental Factors on Carbon Stocks for the Northern Region: The purpose of this report is to expand upon

the previous assessment of baseline carbon stocks across individual national forests, and at the regional scale by attributing those carbon stocks and trends to categories of human-caused factors including land use, timber harvesting, natural disturbances (insects and wildfire), and environment factors including climate variability, increasing atmospheric carbon dioxide concentration, and nitrogen deposition. This report is in draft and is referenced as such.

- Northern Rockies Adaptation Partnership (NRAP): This partnership is a "science-management" collaboration with the goals of (1) assessing vulnerability of natural resources and ecosystem services to climate change and (2) developing science-based adaptation strategies that can be used by national forests to understand and mitigate the negative effects of climate change. The Northern Rockies region includes the U.S. Forest Service Northern Region 1 and the adjacent Greater Yellowstone area, spanning northern Idaho, Montana, northwest Wyoming, North Dakota, and South Dakota. Five subregions are identified and assessed; the Custer Gallatin National Forest plan area is in the Greater Yellowstone area and the Grassland subregions. The partners involved in the Northern Rockies Adaptation Partnership include the Forest Service, National Park Service, Great Northern Landscape Conservation Cooperative, Plains and Prairie Potholes Landscape Conservation Cooperative, Department of Interior North Central Climate Change Center, Greater Yellowstone Coordinating Committee, Oregon State University, EcoAdapt, Bureau of Land Management, and the U.S. Geological Survey (http://adaptationpartners.org/nrap/). Reports from the partnership are in draft form and referenced as such because final reports were not available at the writing of this assessment.
- Peer-reviewed literature and references: A variety of literature and reference citations were used and are cited in this report.

Current Forest Plan Direction

The current individual forest plans for the Custer and Gallatin National Forests have no direction related to carbon stocks.

Existing Condition

Forests are an important carbon sink according to recent estimates of net annual storage (Pan et al. 2011; USDA Forest Service 2015b). Forests act as carbon sinks because they generally absorb more carbon then they emit, due to growing plants that remove carbon dioxide and store it (USDA 2015a; Heath et al. 2011). In 2003, forests in the U.S. and forest products offset 12-19 percent of U.S. fossil fuel emissions, mainly due to forest growth from past deforestation (Ryan et al. 2010; USDA Forest Service 2015b). Heath (et al. 2011) found that National Forest System lands have 28 percent more carbon density per hectare than that of private forest land ownership. However, private forest lands contain 32 percent more total carbon stocks than national forests, largely because private forest land makes up 63 percent of the forest land compared to 22 percent for National Forest System lands. Land conversions from forest to other uses (such as agriculture or development) exert negative pressure on the carbon sink (Conant et al. 2007; Ryan et al. 2010).

Carbon stocks are discussed and displayed below in terms of total forest ecosystem carbon, carbon-density, carbon flux, and harvested wood products (HWD) for the Northern Region and the Custer Gallatin National Forest where data is available. Total forest ecosystem carbon is found in the seven pools stated below and are displayed in teragrams (Tg), which is equivalent to 2,204,622,621.85 pounds. Carbon density is an estimate of forest carbon stocks (tonnes) per unit area (acres). Tonnes (t) is a metric ton equivalent to 2,204.6 pounds. Carbon flux is the transfer of carbon from one carbon pool to another. Harvested wood products includes all wood material (including bark) that leaves harvest sites.

Baseline carbon stocks from 1990 to 2013 have been estimated on National Forest System land in all the Northern Region units for the following forest ecosystems carbon pools:

- above-ground live tree,
- below-ground live tree,
- standing dead,
- understory,
- down dead wood,
- forest floor and
- soil organic carbon.

The Northern Region has had a steady increase in total forest ecosystem carbon stored from about 1,324 teragrams in 1990 to 1,458 teragrams in 2013 (USDA Forest Service 2015a). Both the Custer and Gallatin National Forests show increases (Figure 2). Eight of the national forests in the Northern Region increased ecosystem forest carbon stocks including the Custer and the Gallatin. The Lewis and Clark, Helena, and Bitterroot National Forests, and the Dakota Prairie Grassland decreased. All seven carbon pools showed a similar pattern of increasing between 1990 and 2013. Since 1990, the highest percent increase occurred in standing dead (38 percent) and the lowest in the below ground (6 percent) pool. The above-ground live tree pool is storing the highest amount and the understory pool the lowest (USDA Forest Service 2015a).

In 2013 the Custer National Forest was storing around 35 teragrams with an increase in the range of 19.5 to 37.7 percent since 1990. The Gallatin National Forest's stored carbon showed a similar trend to about 100 teragrams in 2013.

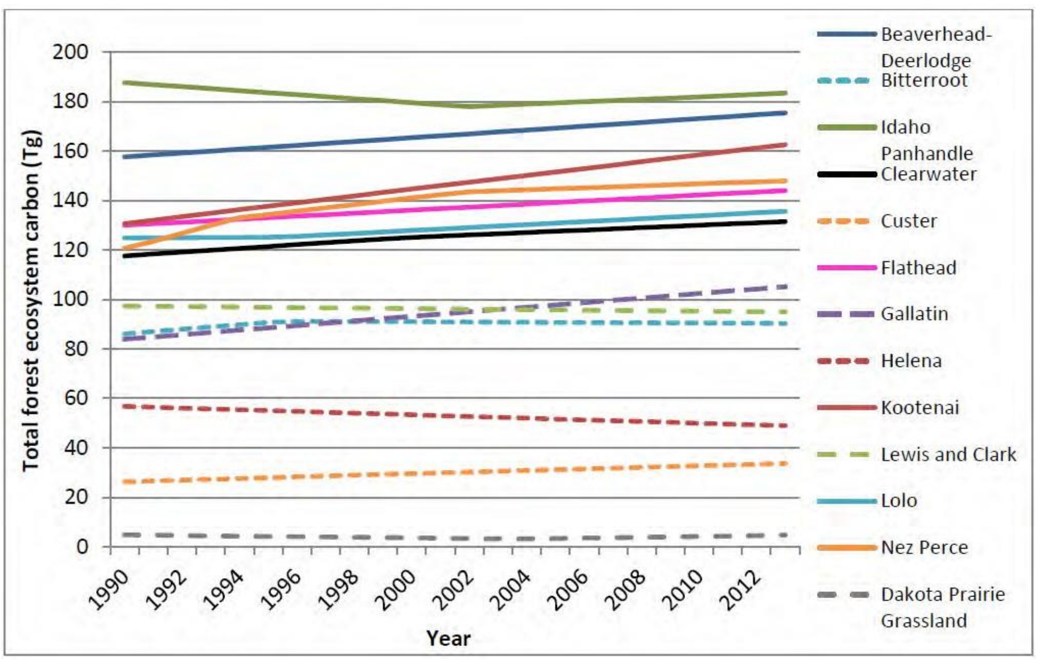

Figure 2. Total forest ecosystem carbon (Tg) for national forests and one grassland in the Northern Region from 1990 to 2013 ***(USDA Forest Service 2015a)***

Carbon density had a slight increase from 64 tonnes per acre in 1990 to 65 tonnes per acre in 2013. In 2013, the range for the Northern Region was 42.3 to 79.1 tonnes per acre (USDA Forest Service 2015a).

The Custer National Forest is the lowest at 42.3 tonnes per acre and has remained fairly constant since 1990 (Figure 3). The Gallatin National Forest has shown a slight increase from about 60 to about 62 tonnes per acre. Factors such as disturbances and changes in land use, including timber harvest, and site quality may be responsible for trends observed across the region.

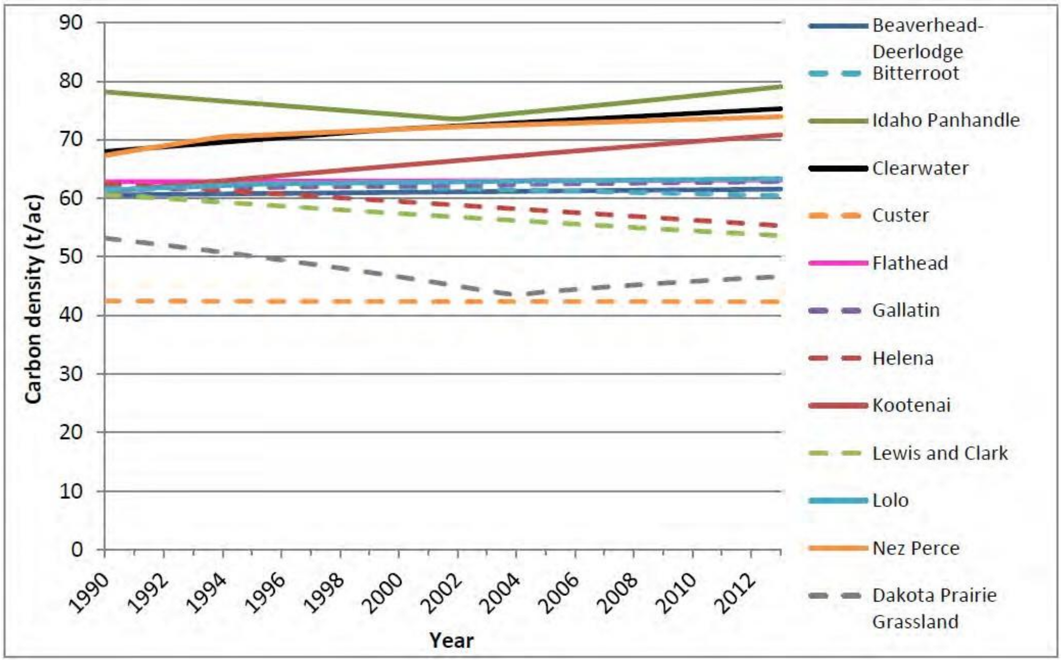

Figure 3. Carbon density (tonnes/acre) for National Forests and Grasslands in the Northern Region from 1990 to 2013 *(USDA Forest Service 2015a)*

Carbon stock change (carbon flux) is the change in carbon stocks over time, calculated by taking the difference between successive inventories and dividing by the number of years between these inventories (Woodall et al. 2013). Figure 4 and Figure 5 display the estimated carbon stock change from 1990 to 2013. The green shaded area represents the uncertainty of the estimate at the 95 percent confidence interval. What this means is that 19 times out of 20 the carbon stock for any given year should fall within the green zone.

A negative change in the graph (Figure 4 and Figure 5) means carbon is being removed from the atmosphere and sequestered by the forests (a carbon sink) while a positive change means carbon is added to the atmosphere by forest-related emissions (a carbon source; USDA Forest Service 2015a). Both the Custer and the Gallatin National Forests at the baseline estimate (1990 to 2013) are carbon sinks; carbon is being sequestered by the national forests. Carbon flux for the Gallatin National Forest is between 0 and -2. For the Custer National Forest, the estimate is between 0 and -1, however small areas within the uncertainty area (green shaded area) are between 0 and +1; there could be a slight chance it acts as a carbon source.

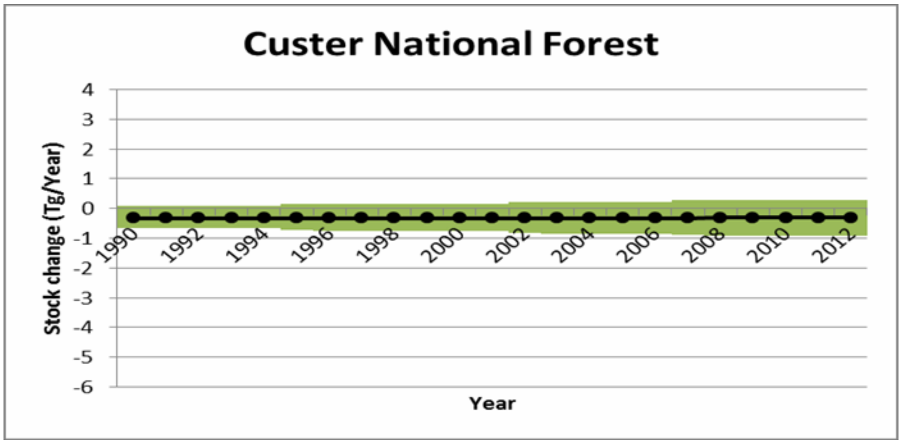

Figure 4. Carbon stock change and uncertainty estimates (95% confidence level) for the Custer National Forest from 1990 to 2012 (USDA Forest Service 2015a)

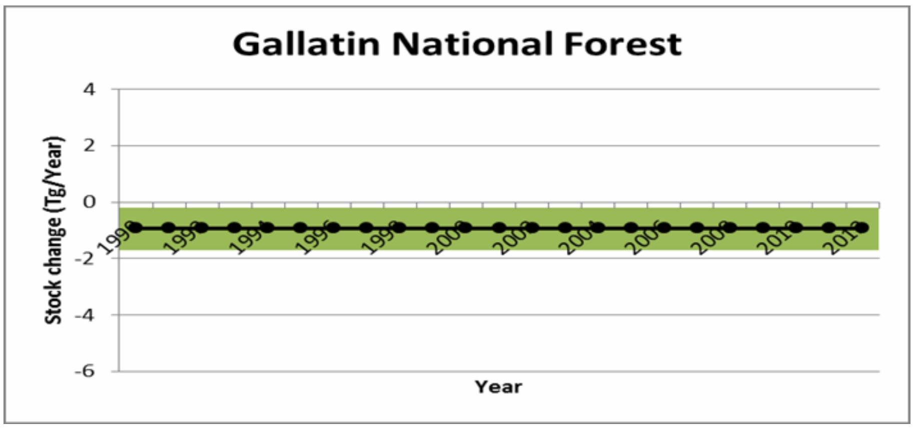

Figure 5. Carbon stock change and uncertainty estimates (95% confidence level) for the Gallatin National Forest from 1990 to 2012 (USDA Forest Service 2015a)

Stand-replacement disturbances (such as severe wildfire) affects stand age and plays a role in determining the distribution of the carbon pools, and carbon flux will change over time as disturbances play out in these systems (Pregitzer and Euskirchen 2004). As an example, recent large wildfires (2012 Ash fire and 2012 Millie fire) may weaken sequestration levels in the future. As these forests grow back and develop, the strength of the carbon sink increases until peaking at an intermediate age and then gradually declining but remaining positive. Carbon stocks continue to accumulate as stands mature, although at a declining rate, until impacted by a disturbance.

Increasing social interest in mitigating rising atmospheric carbon dioxide levels has focused attention on storage of forest carbon, including harvested wood products, which is an important carbon pool that should be considered in decision making associated with carbon monitoring and climate change adaptation and mitigation (Stockmann et al. 2012). Harvested wood products are a small fraction of the carbon pool compared to ecosystem carbon, however it is an important component of national level carbon accounting and reporting (USDA Forest Service 2015a; Stockmann et al. 2012). Products made from wood including lumber, panels, paper, paperboard, and wood used for fuel are all harvested wood products (Stockman et al. 2012). The harvested wood products pool includes both products in use and products that have been discarded to solid waste disposal sites. Regional harvest cut-and-sold reports were used to track the cycle of carbon from harvest to timber product to primary wood products to end use to disposal (USDA Forest Service 2015a). Harvesting ads to the harvested wood products pool.

Prior to the 1940s, events like the Great Depression contributed to low levels of harvest in the Northern Region. After 1940, harvest levels steadily increased till a peak in 1968 (USDA Forest Service 2015a). In the early 1990s harvest levels sharply declined to a low in 2007. Since this period, harvest levels have had a slight increase and remained relatively low.

In 1955, total carbon stored took a jump, with a steady increase until peaking in 1995 with approximately 34 teragrams in storage (Figure 6; USDA Forest Service 2015a). Since 1995, carbon storage has decreased to 32 teragrams. As indicated earlier, timber harvest declined in the mid-1990s resulting in less harvested wood products carbon being added to the pool. This depicts the influence of timber harvest on the harvested wood products pool. It is estimated that the harvested wood products carbon stocks in the Northern Region represent 2.16 percent of the total forest carbon storage in 2012. The Northern Region harvested wood products pool is now in a period of negative net annual stock change because the decay of products harvested between 1906 and 2010 exceeds additions of carbon to the harvested wood products pool through harvest (Stockmann et al. 2012). Harvested wood products are currently not estimated for the Custer and Gallatin National Forests individually. However, harvest levels on the Montane units generally follow a similar trend, with a very sharp decline from 2000 to 2009 (Terrestrial Vegetation – Forested Report, Sandbak, 2016). The prairie units peaked in the 1980s and another elevated level in 2000 to 2009.

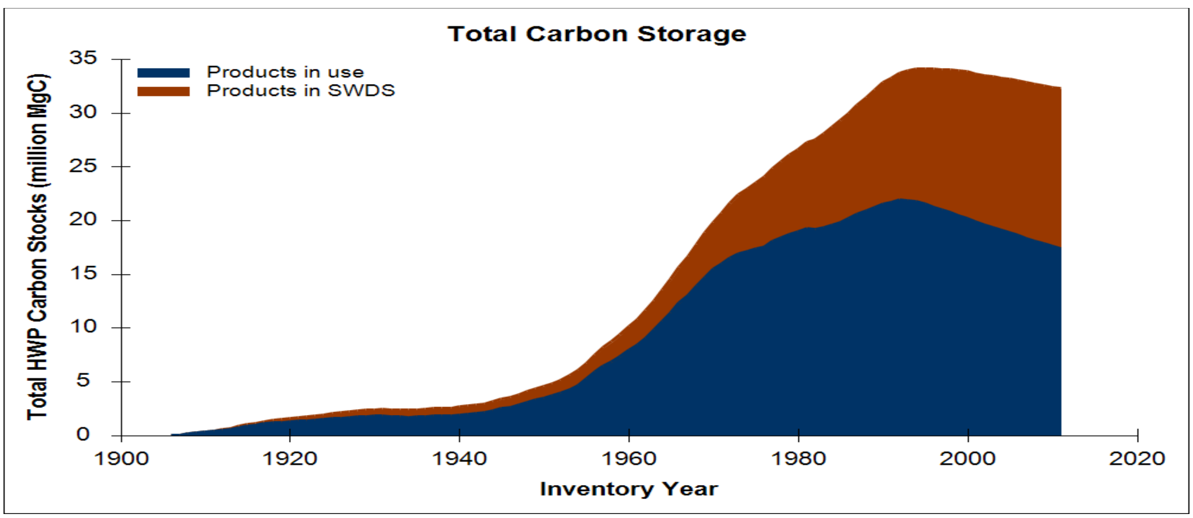

Figure 6. Cumulative total carbon stored in harvested wood products manufactured from Northern Region timber. Carbon in harvested wood products (HWP) includes both products that are still in use and carbon stored at solid waste disposals sites (SWDS), including landfills and dumps (Stockmann et al. 2012).

For the baseline period (1990 to 2013) total forest carbon (forest ecosystem and harvested wood products carbon) is estimated at 5.83 teragrams carbon per year for the Northern Region (USDA Forest Service 2015a). This represents the net sequestration rate of carbon by forests in the Northern Region.

Key Benefits to People

Carbon stocks can be affected by disturbance such as wildfires, insect activity, timber harvesting and climate change as discussed above. See the Benefits to People section of the Terrestrial Vegetation (Forested) report (Sandbak 2016) and the Timber report (Thornburgh 2016).

Trends and Drivers

Also see the Trends and Drivers section of the Terrestrial Vegetation (Forested) report (Sandbak 2016).

Trends

Assessing, understanding and measuring forest carbon pools and flows are complicated when considering the cycle of forest growth, death, and regeneration and the use of wood removed (Ryan et al. 2010). Additional factors that may impact this cycle adds to the complexity. Disturbances such as drought, forest fires, and insect outbreaks may substantially reduce carbon stocks (Galik and Jackson 2009). This brings uncertainty in the long-term ability of forests to persist as net carbon sinks. In addition, climate change threatens to amplify risks to forest carbon stocks by increasing the frequency, size, and severity of disturbances (Dale et al. 2001, Breashears and Allen 2002, Westerling and Bryant 2008, Running 2006, Littell et al. 2009, Boisvenue and Running 2010, USDA Forest Service 2015b). This may limit post-disturbance forest regeneration, shifting forests to non-forested vegetation and possibly converting areas from a carbon sink to a carbon source with increased severity of disturbance and projected climate changes (Strom and Fule 2007, Kurz et al. 2008, Galik and Jackson 2009, Turner et al. 2012). Non-regenerating forests present a large risk to carbon storage, which is likely impeded by climate change; for this reason, promoting regeneration to avoid forest loss should receive a high priority (Ryan et al. 2010).

From 1600 to 1800, forests in the United States were in approximate carbon balance with the atmosphere (USDA Forest Service 2012). A large pulse of carbon emissions during the 19th century occurred as a result of utilization and land clearing, followed by a net carbon sequestration from forest regrowth in the 20th century. Recent data and knowledge of forests after disturbances suggest a decline in rate of forest carbon sequestration. If insect and wildfire disturbances increase as expected, forests will emit greater amounts of carbon (Vose et al. 2012). Forested area is expected to decline between 2010 and 2060 primarily due to lands that are converted to urban and other land uses (USDA Forest Service 2012). Carbon stored in U.S. forests is projected to peak between 2020 and 2040 and then decline.

Wildfires, insect activity, timber harvesting and weather events all affect carbon stocks. Currently an assessment is underway for the national forests in the Northern Region on the influence of disturbance, management activities, and environmental factors on carbon stocks for the period 1990 to 2011 (USDA Forest Service 2016). Corporate Forest Service monitoring data, management records and management tools, complemented with forest change information from the Landsat series of satellites is being used. The intent of the assessment is to provide a summary of the effects of land management, natural disturbances, and environmental factors on the forest carbon dynamics on forest system lands. This is currently in draft. Preliminary findings for the Northern Region and the Custer Gallatin National Forest include the following.

Northern Region (USDA Forest Service 2016)

- Forest carbon trends in the Northern Region have been strongly influenced by the history of land use and policies as well as climate change. Northern Region national forests have generally experienced a switch from carbon sinks to carbon sources and a decline in accumulated carbon. Declining carbon stocks are largely due to disturbances and aging effects, which can be explained by timing of Euro-American settlement, stand age relationships, and recent disturbances. Stand age in 2010 indicated that majority of stands in the Northern Region are more than 80 years old, with a distinctive pulse of in establishment from about 1900 to 1930, likely due to fires around 1989 and 1910. Fire suppression likely allowed more stands to survive and continue growing reaching maximum productivity between 30 and 60 years. This corresponds approximately to the period of 1951 to early 1980 when the Northern Region's forests were carbon sinks. These stands by the 1980s aged past their peak productivity and switched to carbon sources with declining carbon accumulation.

- Recent disturbances indicate another pulse of establishment of young stands (less than 20 years old) between 1990 and 2010, suggesting reforestation after large severe disturbances (mostly fire). Initially these recent disturbances increased carbon emissions and in the coming decades they will reach maximum productivity. This may result in greater carbon accumulations and these forests will become carbon sinks again.
- Climate in the Northern Region has gotten warmer and slightly dryer, and has had a mostly negative effect on carbon stocks. It has also contributed to the switch to a carbon source and loss of carbon.
- The Northern Region is expected to get even warmer and potentially dryer in the future, which may intensify the already negative climatic effects.
- Atmospheric carbon dioxide concentrations are expected to continue increasing for the foreseeable future, potentially counteracting negative effects of climate.
- A few Northern Region national forests experienced a gain of forest carbon with most forests experiencing a loss. Overall the Northern Region had approximately 74 teragrams carbon loss between 1950 and 2010. Most of the carbon loss was in the live biomass carbon pools (above ground and below ground) and forest floor carbon pools, while the soil and dead wood pools saw small carbon gains.

Custer National Forest (USDA Forest Service 2016)

- Disturbances - Fire has had the largest effect on carbon storage (86 percent), followed by harvest (13 percent), and then insects (1 percent). Most notable reduction in carbon storage from these disturbances was found in 1996, with a continuing downward trend to 2011. These trends mirror the temporal pattern of the disturbances.
- Forests from 1951 to 1993 maintained a small carbon sink. Recent disturbances have switched to mostly a carbon source.
- About 22 percent of forests are less than 10 years old; reflecting the establishment and regrowth after fire and harvest disturbances in 2006, 2008, and 2009. These occurred primarily in the ponderosa pine stands on the pine savanna units. At about 35 years of age they will be at peak productivity suggesting carbon may potentially accumulate rapidly in about two decades and forests may switch to a carbon sink again. Negative influences from disturbances in the 2000s suggest forests have not yet recovered carbon.
- Variable climate resulted in fluctuations between a carbon source and a carbon sink from 1951 to 1993. The past two decades of climate effects on changing carbon stocks have been mostly negative, likely due to warming temperatures increasing soil respiration and causing water stress.

- Since 1951 forests have accumulated carbon due to increases in nitrogen deposition and atmospheric carbon dioxide, enhancing the carbon sink.
- On the Custer National Forest there has been a net gain of approximately 6.4 teragrams carbon from 1951 to 2010 even with recent carbon losses due to disturbances and climate effects; likely due to a partial offset from fertilization and nitrogen deposition. All carbon pools increased, with soil carbon and dead wood carbon pools with the highest increase. This transfer is from recent fire disturbances from live pools to dead pools. The Custer was one of a few national forests in the Northern Region with increased carbon in the period 1951 to 2010.

Gallatin National Forest (USDA Forest Service 2016)

- Disturbances - Fire has had the largest effect on carbon storage (65 percent), followed by harvest (4 percent), and then insects (31 percent). There was a slight downward trend in carbon storage from these disturbances in the early 1990s. The most notable reduction was found in 2000, with a continuing downward trend to 2011. These trends mirror the temporal pattern of the disturbances.
- From 1951 to 2010 the Gallatin National Forest maintained a small carbon source, while experiencing a downward trend in changing carbon stocks due to negative disturbance aging effects.
- Sixty-six percent of the stand ages are more than 90 years of age with a pulse of stand establishment about 110 to 139 years ago. This time period coincides with Euro-American settlement in the region and the disturbances that followed. Fire suppression enabled stands to survive and continue to grow. These middle to older aged stands have aged past their peak net primary productivity and have been declining in productivity. This has contributed to the decline in forest carbon. Fires and insect outbreaks in 2001 and from 2006 to 2008 have created young stands less than 20 years old on about 17 percent of the stands. This pulse of young stands indicates that forests are recovering and may become a carbon sink in a few decades as they age to maximum productivity.
- While climate effects have fluctuated between positive and negative following the inter-annual variability in climatic variables, increases in atmospheric carbon dioxide concentrations and nitrogen deposition have had positive effects on carbon stocks. From 1994 to 2010, warming temperatures (which can increase soil respiration and water stress and hamper growth) have resulted in a negative climate effect.
- The Gallatin National Forest has experienced a net loss (like most national forests in the Northern Region) of approximately 14 teragrams carbon from 1951 to 2011, due to negative disturbance, aging and climate effects. Most carbon is lost from the above-ground live and forest floor carbon pools.

Future warmer, drier conditions will likely cause more frequent, larger wildfires that will move carbon from biomass storage to the atmosphere (USDA Forest Service 2015a, Kashian et al. 2006). Beetle susceptibility and outbreaks are expected to increase with warmer temperatures and increased drought stress. The ability of forests to sequester carbon depends in part on their resilience to these stressors. Management actions that maintain long-term productivity and reduce the likelihood of high-severity disturbances may help maintain the capacity of a forest to sequester carbon (Galik and Jackson 2009); however, the magnitude and overall potential impact of this is uncertain and depends greatly on the scale considered.

Modeling by Hurteau and North (2009) found that when comparing potential carbon emissions in an unmanaged mixed conifer forest from a wildfire versus one that was managed (prescribed fire or understory thinning), the managed forest had less carbon emissions than the unmanaged forest. Hurteau and others (2008) found that when looking at four large stand-replacing fires in 2002 in the western U.S., silviculture thinning treatments may have decreased carbon emissions by as much as 98 percent.

To an extent, rates of net carbon sequestration in forests may be enhanced through management strategies that: retain and protect forest land from conversion to non-forest uses, restore and maintain resilient forests that are better adapted to a changing climate and other stressors, and reforest lands disturbed by stand-replacing events (USDA Forest Service 2015a).

Millar and others (2007) have encouraged management practices be flexible and for mangers and planners to remain informed about emerging climate science and to use that knowledge to assist in their management decisions. Resource managers will be challenged to integrate adaptation and mitigation strategies to incorporate climate change. Millar and others (2007) have described these strategies and options as follows:

- *Adaptation strategies* are actions that help ecosystems accommodate changes adaptively. Adaptation strategies may include options such as *resistance* (forestall impacts and protect highly valued resources), *resilience* (improve the capacity of ecosystems to return to desired conditions after disturbance), and *response* (facilitate transition of ecosystems from current to new conditions).
- *Mitigation strategies* include actions that enable ecosystems to reduce human-caused influences on global climate. Mitigation strategies include options to sequester carbon and reduce greenhouse gas emissions.

Strategies that can increase forest carbon storage, prevent its loss, and reduce fossil fuel consumption have risks, uncertainties, and important tradeoffs (Ryan et al. 2010). Thinning, prescribed fire, and other silvicultural actions are often suggested as adaptation actions because they may increase resilience and increase the likelihood of sustaining carbon in the long-term (Millar et al. 2007; Joyce et al. 2008; Ryan et al. 2008). However, timber harvest can reduce carbon stocks in the short term, but may improve sequestration over time by promoting growth and resiliency. Harvested wood is of additional importance; treatments that generate long-lived wood products such as lumber and furniture transfer ecosystem carbon to the harvested wood products pool (USDA Forest Service 2015a). Forest vegetation treatments also generate excess material (woody biomass) which, if utilized, can be a renewable energy substitute for fossil fuels. Avoiding deforestation associated with land use changes and providing for prompt reforestation after disturbance ensures that forests remain carbon sinks over time; these actions have few risks. Strategies such as decreasing harvest can increase diversity and retain carbon, but there is risk in products being harvested elsewhere and potential carbon lost in disturbances (Ryan et al. 2010). Recognizing the tradeoffs is vital to promote forest carbon storage, and the other benefits offered by forests should be considered along with carbon storage potential.

The Forest Service has recently identified principles and guidelines for carbon stewardship (USDA Forest Service 2015a). These are intended to be refined, updated, and formally approved based on field experience, emerging science, and higher level policy revisions and interpretations across the full range of Forest Service programs and authorities.

- Emphasize ecosystem function and resilience

- Recognize carbon sequestration as one of many ecosystem services
- Support diversity of approach in carbon exchange and markets
- Consider system dynamics and scale in decision making
- Use the best information and methods to make decisions about carbon management
- Strive for program integration and balance

The principles and guidelines above are not meant to imply that maximizing forest carbon storage should be the objective of any forest plan or that carbon should be the most important or overriding purpose of forest plans or project actions (USDA Forest Service 2015a). Elevating carbon storage as the primary focus could potentially impede other co-benefits and ecosystem services and would be short-sighted (Ryan et al. 2010).

Information Needs

Uncertainty exists regarding ecosystem carbon stocks. The source for carbon estimates used in the report (USDA Forest Service 2015a) for the Northern Region is based on an analysis of forest inventory and analysis (FIA) data with the carbon calculation tool conducted by the Climate Change Advisor's Office. The Carbon Calculation Tool is the official reporting tool for interpreting historical forest inventory and analysis data to develop timelines of carbon stock estimates, and while there are uncertainties, it is the best nationally available integration of historical and current inventory designs to identify trends in carbon storage. Research is underway to refine the modeling of forest floor carbon stocks and initial results of this work suggest that the existing model may be overestimating forest floor carbon. Refinements are planned in regard to the pools of soil organic carbon, belowground biomass, understory vegetation, and woodland-versus-forest delineations.

Forest inventory and analysis data used for this analysis was the most recent measurements and large severe wildfires on the Custer Gallatin National Forest since 2012 are not reflected. These fire areas will create another pulse of young stands and in a few decades may become a carbon sink as they are reforested and age to maximum productivity. Additional uncertainty with forest inventory and analysis data include sampling error, measurement error, and the lack of temporal sensitivity that results from the nature of the remeasurement cycle (USDA Forest Service 2015a). The uncertainty of forest carbon stock change at the national scale often ranges between 20-30 percent, suggesting that uncertainty simulations at smaller scales should exceed 30 percent.

Stockman and others (2014) identified sources of uncertainty in the estimate of carbon stored in harvested wood products that included: reported harvest, timber product ratios, primary product ratios, conversion factors, end use product ratios, product half-lives, disposition ratios, decay limits, landfill half-lives, dump half-lives, burned with energy capture ratio, and the adjustments of land base over time. The estimated, based on an analysis of uncertainty the range of actual values may differ from predicted values by +/- 5 to 30 percent (Stockmann et al. 2014).

There is uncertainty regarding the accurate representation of climate change, carbon, cycles, and the potential for forest management to influence them on a meaningful scale. Assessments on forest carbon disturbances are currently being developed which may help inform managers and the public of the relationship between carbon storage, past management, and disturbances to begin considering the short and long-term carbon consequences of alternative forest management strategies (USDA Forest Service 2015a). In the Northern Region, this effort is underway as reported earlier with some of the initial findings to date.

Although current levels of uncertainty regarding carbon stocks are high—with ongoing research geared towards reducing these uncertainties—this should not exclude managers from using initial carbon baselines to engage in learning more about forest carbon (USDA Forest Service 2015a). It is unclear how carbon storage goals may interact with other desired conditions or services such as biodiversity, sustainability, clean water and air, and wildlife habitat needs in dynamic and complex ecosystems. But with continued research, monitoring and modeling we can improve our understanding of system drivers and response to disturbances (fire, insects, and climate change) and their impacts to carbon stocks (USDA Forest Service 2015b).

Key Findings

Total Forest Ecosystem Carbon

- The Northern Region has had a steady increase in total forest ecosystem carbon stored from about 1,324 teragrams in 1990 to 1,458 teragrams in 2013.
- In 2013 the Custer National Forest was storing around 35 teragrams with an increase in the range of 19.5 to 37.7 percent since 1990.
- The Gallatin National Forest's stored carbon showed a similar trend to about 100 teragrams in 2013.

All seven carbon pools showed a similar pattern of increasing between 1990 and 2013 in the Northern Region. Since 1990, the highest percent increase occurred in standing dead (38 percent) and the lowest in the below ground (6 percent) pool. The above-ground live tree pool is storing the highest amount and the understory pool the lowest. For the baseline period (1990 to 2013) total forest carbon (forest ecosystem and harvested wood products carbon) is estimated at 5.83 teragrams carbon per year for the Northern Region (USDA Forest Service 2015a). This represents the net sequestration rate of carbon by national forests in the Northern Region.

Carbon Density

- Carbon density had a slight increase from 64 tonnes per acre in 1990 to 65 tonnes per acre in 2013. In 2013, the range for the Northern Region was 42.3 to 79.1 tonnes per acre.
- The Custer National Forest is the lowest at 42.3 tonnes per acre and has remained fairly constant since 1990.
- The Gallatin National Forest has shown a slight increase from about 60 to about 62 tonnes per acre.

Factors such as disturbances and changes in land use, including timber harvest, and site quality may be responsible for trends observed across the region.

Carbon Flux

- Both the Custer and the Gallatin National Forests at the baseline estimate (1990 to 2013) are carbon sinks; carbon is being sequestered by the national forests. On the Custer there could be a slight chance it acts as a carbon source.

Carbon in Harvested Wood Products

- Carbon stocks continue to accumulate as stands mature, although at a declining rate, until impacted by a disturbance.

- In 1955 across the Northern Region, total carbon stored took a jump, with a steady increase until peaking in 1995 with approximately 34 teragrams in storage.
- In the Northern Region since 1995 carbon storage has decreased to 32 teragrams. As indicated earlier, timber harvest declined in the mid-1990s resulting in less harvested wood products carbon being added to the pool.
- This depicts the influence of timber harvest on the harvested wood products pool. It is estimated that the harvested wood products carbon stocks in the Northern Region represent 2.16 percent of the total forest carbon storage in 2012.
- The Northern Region harvested wood products carbon pool is now in a period of negative net annual stock change because the decay of products harvested between 1906 and 2010 exceeds additions of carbon to the harvested wood products pool through harvest.

Influence of Disturbance, Management Activities, and Environmental Factors on Carbon Stocks for the Period 1990 to 2011

- **Custer National Forest -** Fire has had the largest effect on carbon storage (86 percent), followed by harvest (13 percent), and then insects (1 percent). There has been a net gain of approximately 6.4 teragrams carbon from 1951 to 2010 even with recent carbon losses due to disturbances and climate effects; likely due to a partial offset from fertilization and nitrogen deposition. All carbon pools increased, with soil carbon and dead wood carbon pools having the highest increase. This transfer is from recent fire disturbances from live pools to dead pools. The Custer National Forest was one of a few forests in the Northern Region with increase in the period 1951 to 2010.
- **Gallatin National Forest -** Fire has had the largest effect on carbon storage (65 percent), followed by harvest (4 percent), and then insects (31 percent). The Gallatin National Forest has experienced a net loss (like most forest in the Northern Region) of approximately 14 teragrams carbon from 1951 to 2011, due to negative disturbance, aging and climate effects. Most carbon is lost from the above-ground live and forest floor carbon pools.

Rates of net carbon sequestration in forests may be enhanced through management strategies that retain and protect forest land from conversion to non-forest uses, restore and maintain resilient forests that are better adapted to a changing climate and other stressors, and reforest lands disturbed by stand-replacing events.

However, there is uncertainty regarding the accurate representation of climate change, carbon, cycles, and the potential for forest management to influence carbon stocks.

Uncertainty

- Although current levels of uncertainty regarding carbon stocks are high—with ongoing research geared towards reducing these uncertainties—this should not exclude managers from using initial carbon baselines to engage in learning more about forest carbon.
- With continued research, monitoring and modeling we can improve our understanding of system drivers and response to disturbances (fire, insects, and climate change) and their impacts to carbon stocks.

The long-term capacity of forest ecosystems to sequester and store carbon depends in large part on their health, resilience and adaptive capacity (USDA Forest Service 2016). And because ecosystems are dynamic, they are increasingly affected by many factors such as multi-year droughts, insect and disease epidemics, wildfires, and catastrophic storms, which all have an impact on carbon storage.

The Forest Service's approach to managing carbon is through managing the health of the nation's forests (USDA Forest Service 2016). Forest management strategies that include retaining and protecting forest land from conversions to non-forest uses, restoring and maintaining resilient forests that are better adapted to a changing climate and other stressors, and reforesting lands disturbed by catastrophic wildfires and other natural events will assist in managing risks to the net carbon sequestration flow over time.

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